United States
Department of
Agriculture

Soil
Conservation
Service

Soil Mechanics Training Series

Basic Soil Properties

Module 4 - Volume - Weight Relations

Study Guide

ENG - SOIL MECHANICS TRAINING SERIES

(BASIC SOIL PROPERTIES)

MODULE 4 - VOLUME-WEIGHT RELATIONS

National Employee Development Staff
Soil Conservation Service
United States Department of Agriculture
November 1986

Preface

The design and development of this training series are the results of concerted efforts by practicing engineers in the SCS. The contributions of many technical and procedural reviews have helped make this training series one that will provide basic knowledge and skills to employees in soil mechanics.

The training series are designed to be a self study and self paced training program.

The training series, or a part of the series, may be used as refresher training. Upon completion of the training series, participants should have reached the ASK Level 3, perform with supervision. The modules for the training series will be released as they are developed.

ENG - SOIL MECHANICS TRAINING SERIES
(BASIC SOIL PROPERTIES)
MODULE 4 - VOLUME-WEIGHT RELATIONS

CONTENTS

INTRODUCTION

This training module on Volume-Weight Relations is 1 of 6 modules of the ENG-Soil Mechanics Training Series (Basic Soil Properties). Soil Mechanics Level I contains Modules 1 through 3. The modules in the Soil Mechanics Training Series (Basic Soil Properties) are:

Module 4 - Volume-Weight Relations

Module 5 - Compaction

Module 6 - Effective Stress Principal

Module 7 - Qualitative Engineering Behavior by USCS Class

Module 8 - Estimated Soil Properties Table

Module 9 - Qualitative Embankment Design

INSTRUCTION

During the presentation you will be asked to STOP the machine and do activities in your Study Guide. These activities offer a variety of learning experiences and give you feedback on your ability to accomplish the related module objectives. You will need a calculator to do many of the activities.

Module 4 has four objectives to be accomplished. The ability to review and study your material at your desk, while traveling, or in any easy chair makes a self-paced training package beneficial. If you have difficulty with a specific area, study, re-study, and, if necessary, get someone to help you. DO NOT continue until you can complete each objective.

You should complete this module as follows:

1. Read the objectives.

2. Run the slide/audio cassette, stopping it when you need to work in the Study Guide.

3. Study and review all references.

If you have difficulty in a specific area, contact your State Engineering Staff, through your supervisor.

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1 Slide Tray

1 Audio Cassette

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ENG - SOIL MECHANICS TRAINING SERIES

(BASIC SOIL PROPERTIES)

MODULE 4 - VOLUME-WEIGHT RELATIONS

STUDY GUIDE

November 1986

ACTIVITY 1 - OBJECTIVES

At the completion of this module you will be able to:

1. Construct a block diagram of a soil mass. From memory, label each of the nine elements with its proper symbol.

2. Define conceptually the most important volume - weight relationships from a list.

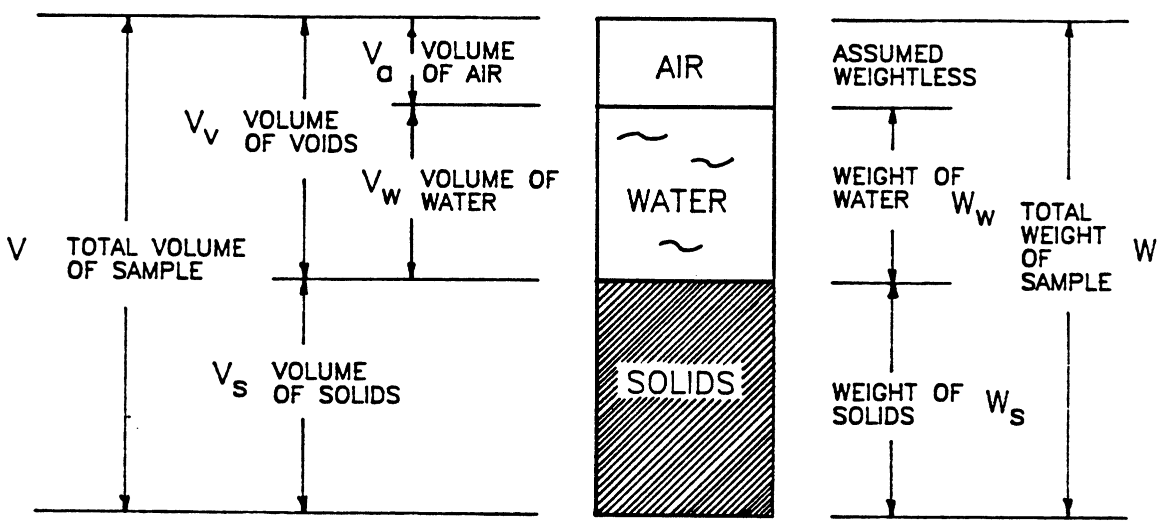
3. Select the proper equations from a given reference table to solve for unknown volume-weight terms.

4. List from memory the four commonly measured laboratory parameters of a soil mass.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 2 - Block Diagram

BLOCK DIAGRAM



W = Total weight of soil mass

W_a = Weight of air (assumed = 0) in soil mass

W_w = Weight of water in soil mass

W_s = Weight of soil solids in soil mass

V = Total volume of soil mass

V_a = Volume of air in soil mass

V_w = Volume of water in soil mass

V_s = Volume of soil solids in soil mass

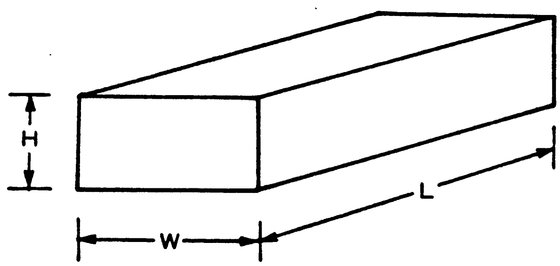
V_v = Volume of voids = V_a+V_w = $V-V_s$

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 3 - Examples of Volume Calculations

Volumes of regularly shaped objects may be calculated by the following equations:

For a rectangular prism body, $V = W \times L \times H$



Example

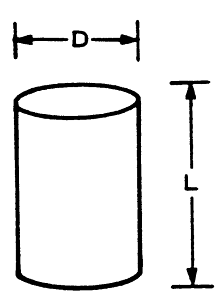
A soil block is 12" long, 4" high, and 6" wide. What is its volume, in cubic inches?

$V = W \times L \times H$

$V = 6'' \times 12'' \times 4''$

$V = 288$ cubic inches

For a cylindrical specimen $V = \frac{\pi D^2}{4} \times L$, where $\pi = 3.14$



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ACTIVITY 3 - Continued

Example

A cylindrical specimen is 8 cm in diameter and 20 cm long. What is its volume, in cubic centimeters.

$V = \frac{\pi D^2}{4} \times L$, where π is a constant value of 3.14.

$$V = \frac{3.14 \times 8^2}{4} \times 20$$

$$V = 1004.8 \text{ cm}^3$$

WORK THE TWO PROBLEMS ON THE NEXT PAGE TO COMPLETE THIS ACTIVITY.

ACTIVITY 3

Problems

1. A soil sample is obtained in a cylindrical tube. The tube has an inside diameter of 2-7/8 inches. The sample is 17.5 inches long. What is the volume of the sample in cubic inches?

2. What is the volume of the above sample in cubic centimeters? (Hint 1" = 2.54 centimeters)

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON THE FOLLOWING PAGE

ACTIVITY 3

Solutions

1. $V = \frac{\pi D^2}{4} \times L$

$$V = \frac{3.14 \times 2.875^2}{4} \times 17.5$$

$V = 113.6$ cubic inches

2. 1 cubic inch = $2.54 \times 2.54 \times 2.54$ cubic centimeters

= 16.387 cubic centimeters

$(113.6)(16.387) = 1862$ cubic centimeters

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 4

The unit weight of pure water is a constant value for a given temperature. Unit weight is defined as the weight of a substance divided by the volume of the substance. The unit weight of water is usually denoted γ_w. It may be expressed in equation form.

$$\gamma_w = \frac{W_w}{V_w}$$

The greek letter gamma, γ, is used to symbolize unit weight. The unit weight of water in commonly used units is 62.4 pounds per cubic foot or 1.0 grams per cubic centimeter.

Since the unit weight of water is a constant, known value, if we weigh a given amount of water, we can determine its volume.

Example

Given that the unit weight of water is 62.4 pounds per cubic foot and a body of water weighs 28 pounds, find the volume of the water.

1. Rearrange the above equation:

$$V_w = \frac{W_w}{\gamma_w}$$

$$V_w = \frac{28.0 \text{ pounds}}{62.4 \text{ pounds/ft}^3}$$

$$= 0.449 \text{ ft}^3$$

Problem: Given a soil sample weighs 250 grams before drying, 160 grams after drying. What is the volume of water in the sample expressed in cubic centimeters?

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON THE FOLLOWING PAGE

ACTIVITY 4

Solution

The weight of water in the sample is the difference in weight before drying and after drying.

$$W_w = W - W_s$$

$$= 250 \text{ g.} - 160 \text{ g.}$$

$$V_w = \frac{W_w}{\gamma_w}$$

$$= \frac{90 \text{ grams}}{1 \text{ gram/cubic centimeter}}$$

$$= 90 \text{ cubic centimeters}$$

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 5 - SPECIFIC GRAVITY

The specific gravity of a substance is the ratio of the unit weight of that substance to the unit weight of water at 20 degrees centigrade. This is expressed in equation form as:

$$G = \frac{\gamma_{substance}}{\gamma_{water}}$$

The specific gravity of a soil's solids is abbreviated G_s. This value is the ratio of the unit weight of the soil solids condensed into a solid mass to the unit weight of water. The equation for specific gravity using terms from the block diagram is:

$$G_s = \frac{W_s/V_s}{\gamma_{water}}$$

A laboratory test may be performed to determine the specific gravity of the soil soilds. However, in some field situations, this data may not be available, and an estimate must necessarily be used.

The specific gravity of a soil depends on the mineralogy of the soil grains. Most soils are a blend of several basic minerals such as quartz, feldspar, hornblende, biotite, calcite, and others. An estimate of the constituents of a soil is helpful in estimating a value for the soil's specific gravity.

The specific gravity of some of the more important soil minerals is shown in the following table:

Mineral	Specific Gravity	Mineral	Specific Gravity
Montmorillonite	2.65-2.8	Dolomite	2.87
Kaolinite	2.6	Hornblende	3.2-3.5
Illite	2.8	Magnetite	5.17
Chlorite	2.60-3.00	Quartz	2.66
Calcite	2.72	Biotite	3.0-3.1

Many sands and gravels are composed primarily of quartz. A value of 2.66 is commonly assumed for specific gravity for these soils. Specific gravities of sands and gravels derived from granites or limestones might be higher.

Soils with a high percentage of silt-size particles usually have a specific gravity value of about 2.68, since quartz is usually a major constituent, and small additional amounts of clay minerals slightly increase the value.

Clay soils may have specific gravity values ranging from about 2.60 to 2.80. An average value of 2.7 is commonly assumed. Soils which contain a large amount of micaceous flakes and soils with significant amounts of hematite or magnetite may have quite high specific gravities, ranging from 2.75 to 3.3. Test data is usually required to accurately determine specific gravities for these unusual soils.

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 6

From the definition of specific gravity, the equation for the specific gravity of soil solids may be stated as:

$$G_s = \frac{(W_s/V_s)}{\gamma_w}$$

If we know values of specific gravity of the solids, G_s, the weight of the solids, W_s, and the unit weight of water, γ_w, the only unknown term on this equation is V_s. Rearranging the equation,

$$V_s = \frac{W_s}{G_s\ \gamma_w}$$

You will recall the source of these measurements as follows:

W_s - weight of a soil mass after drying.

G_s - specific gravity of the soil solids measured in a laboratory or estimated from a table.

γ_w - unit weight of water, 62.4 pounds per cubic foot or 1.0 grams per cubic centimeters.

Example

A soil sample has an oven dry weight of 2.21 pounds. The specific gravity of the soil solids, measured in a laboratory, was 2.70. What is the volume of the soil solids?

$$V_s = \frac{W_s}{G_s\ \gamma_w}$$

$$= \frac{2.21 \text{ pounds}}{2.70 \times 62.4 \text{ pounds/ft}^3}$$

$$= .0131 \text{ ft}^3$$

WORK THE PROBLEM ON THE FOLLOWING PAGE TO COMPLETE THIS ACTIVITY

ACTIVITY 6

Problem

A soil sample has a total volume of 1,587 cubic centimeters. The specific gravity of the soil solids is 2.68. The oven dry sample weight is 2,380 grams. What is the volume of the voids in the sample?

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON THE FOLLOWING PAGE

ACTIVITY 6 - Solution

Given:

$V = 1587$ cubic centimeters

$G_s = 2.68$

$W_s = 2,380$ grams

Solution:

$$V_s = \frac{W_s}{G_s\ \gamma_w}$$

$$= \frac{2,380 \text{ grams}}{2.68 \times 1.0 \text{ grams/cm}^3}$$

$= 888.1$ cubic centimeters

$$V_v = V - V_s$$

$$= 1587 \text{ cm}^3 - 888.1 \text{ cm}^3$$

$$= 698.9 \text{ cm}^3$$

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 7 - WATER CONTENT AND PERCENT SATURATION

Water content is the ratio of the weight of water, W_w, in a soil mass to the weight of soil solids, W_s, in the mass. It is usually expressed as a percentage and is calculated by the equation.

$$w(\%) = \frac{W_w}{W_s} \times 100$$

The weight of water is usually determined by first weighing a sample in its moist state, drying the sample, and then weighing the dry sample. The equation could also be stated as:

$$w(\%) = \frac{W-W_s}{W_s} \times 100$$

Water contents determined on moist soils are usually denoted as w_n. Water contents determined on saturated samples, or a theoretical saturated water content calculated as shown later in the Module, are denoted as w_{sat}.

Percent saturation is defined as the ratio of the volume of water in a soil to the volume of voids, expressed as a percentage. In equation form,

$$S\ (\%) = \frac{V_w}{V_v} \times 100$$

A soil which has its void space filled with water has $V_w = V_v$ and $S(\%) = 100$.

Another definition of percent saturation is the ratio of a soil's natural water content to its saturated water content, expressed as a percent. In equation form,

$$S\ (\%) = \frac{w_n(\%)}{w_{sat}(\%)} \times 100$$

Example

1. A sample is weighed in a moist condition. It weighs 4.20 pounds. After drying in an oven overnight, the sample weighs 3.65 pounds. Calculate the water content.

$$w(\%) = \frac{4.20-3.65}{3.65} \times 100 = 15.1\%$$

Example

2. A moist sample of soil is weighed in a metal container. The soil and con tainer weigh 126.3 grams. The container weighs 13.6 grams. After drying, the sample and container weigh 104.2 grams. Calculate the water content.

CONTINUE TO NEXT PAGE

The weight of water, W_w will be the weight of soil + container before drying minus the weight of the soil + container after drying. The container weight is not affected by drying.

$$W_w = 126.3 - 104.2 = 22.1 \text{ grams}$$

The weight of soil solids is equal to the weight of the sample and container after drying minus the container weight.

$$W_s = 104.2 - 13.6 = 90.6 \text{ grams}$$

Then $w(\%) = \frac{W_w}{W_s} \times 100$

$$= \frac{22.1}{90.6} \times 100.$$

$$= 24.4\%$$

CONTINUE TO NEXT PAGE

ACTIVITY 7 - Continued

Problem 1. An air dry sample weighs 269 grams. An amount of water weighing 27.9 grams is added to the dry soil and well mixed. What is the resulting water content of the mixture?

Problem 2. A soil sample is obtained in a tube. The tube was previously weighed and its weight is 1.15 pounds. The weight of the tube and soil sample is 2.07 pounds. The soil sample was pushed from the tube and dried in an oven. The dry sample weight is 0.27 pounds. What is the water content of the sample? If the soil sample's theoretical saturated water content were 262.3%, what is the percent saturation of the sample?

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON THE FOLLOWING PAGE

ACTIVITY 7 - Problem Solutions

1. Given: W_s = 269 grams W_w = 27.9 grams

$$w(\%) = \frac{W_w}{W_s} \times 100$$

$$= \frac{27.9}{269} \times 100$$

$$= 10.4\%$$

2. Given: W_{tube} = 1.15 pounds W_{tube} + sample = 2.07 pounds

W_s = 0.27 pounds $W_{sat}(\%)$ = 262.3%

$$W = (W_{tube} + \text{sample}) - W_{tube}$$

$$= 2.07 \text{ pounds} - 1.15 \text{ pounds}$$

$$= 0.92 \text{ pounds}$$

$$W_w = W - W_s$$

$$= 0.92 - 0.27$$

$$= 0.65 \text{ pounds}$$

$$w(\%) = \frac{W_w}{W_s} \times 100$$

$$= \frac{0.65}{0.27} \times 100$$

$$= 240.7\%$$

$$S(\%) = \frac{W_n(\%)}{W_{sat}(\%)} \times 100$$

$$= \frac{240.7}{262.3} \times 100$$

$$= 91.8\%$$

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 8 - UNIT WEIGHT - SOIL MASS

Unit weight is defined as the weight per unit volume of a soil mass. Several types of unit weight may be defined.

Dry Unit Weight

Dry unit weight is the weight of soil solids in a soil mass divided by the total volume of the soil mass.

$$\gamma_d = \frac{W_s}{V}$$

Moist Unit Weight

Moist unit weight is the total weight of soil mass, divided by its volume.

$$\gamma_m = \frac{W}{V}$$

The term is usually applied to soils that are not saturated.

Saturated Unit Weight

Saturated unit weight is the total weight of a saturated soil mass divided by its volume. Note the definition is the same as the moist unit weight above. This is because air has negligible weight.

$$\gamma_{sat} = \frac{W}{V} \text{ (where } V_a = 0\text{)}$$

Submerged Unit Weight, or Buoyant Unit Weight

Buoyant unit weight is the effective weight of a saturated soil sample below the water table. Because soil solids displace water, they are buoyed upwards according to Archimedes principal. The resultant unit weight is expressed by the formula

$$\gamma_b = \gamma_{sat} - \gamma_w$$

Unit Weight of Water

Pure water at 20° C has a unit weight of 62.4 pounds per cubic foot or 1.0 grams per cubic centimeter.

$$\gamma_w = 62.4 \text{ pounds/cubic foot}$$

$$\gamma_w = 1.0 \text{ grams/cubic centimeter}$$

CONTINUE TO NEXT PAGE

Example 1

A soil specimen is measured and its volume is determined to be 0.011 cubic foot. In a moist state, the sample weighs 1.2 pounds. After drying overnight, the sample weight is 1.0 pounds. Determine the moist unit weight and dry unit weight.

$$\gamma_m = \frac{W}{V}$$

$$= \frac{1.20 \text{ pounds}}{0.011 \text{ ft}^3}$$

$$= 109.1 \text{ pcf}$$

$$\gamma_d = \frac{W_s}{V}$$

$$= \frac{1.00 \text{ pounds}}{0.011 \text{ ft}^3}$$

$$= 90.9 \text{ pcf}$$

Problem:

A saturated soil sample weighs 184 grams. After oven drying, the sample weighs 126 grams. The volume of the sample was determined to be 105 cubic centimeters.

Find

The water content, the saturated unit weight, the buoyant unit weight, and the dry unit weight of the sample.

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON PAGE 22

ACTIVITY 8 - Problem Solution

$$w(\%) = \frac{W_w}{W_s} \times 100$$

$$w(\%) = \frac{184-126}{126} \times 100$$

$$= \frac{58}{126} \times 100$$

$$w(\%) = 46.0\%$$

$$\gamma sat = \frac{W}{V}$$

$$\gamma sat = \frac{184 \text{ grams}}{105 \text{ cm}^3}$$

$$\gamma sat = 1.752 \text{ g/cm}^3$$

$$\gamma d = \frac{W_s}{V}$$

$$\gamma d = \frac{126 \text{ grams}}{105 \text{ cm}^3}$$

$$= 1.200 \text{ g/cm}^3$$

$$\gamma b = \gamma sat - \gamma_w$$

$$= 1.752 \text{ g/cm}^3 - 1.0 \text{ g/cm}^3$$

$$= 0.752 \text{ g/cm}^3$$

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 9 - Unit Weight - Water Content Relationships

The following is an example derivation of a useful equation relating water content and unit weight:

(1)	water content, $w = \dfrac{W_w}{W_s}$	definition
(2)	moist unit weight, $\gamma_m = \dfrac{W}{V}$	definition
(3)	dry unit weight, $\gamma_d = \dfrac{W_s}{V}$	definition
(4)	From (2) $V = \dfrac{W}{\gamma_m}$	rearrange equation (2)
(5)	From (3) $V = \dfrac{W_s}{\gamma_d}$	rearrange equation (2)
(6)	Therefore $\dfrac{W}{\gamma_m} = \dfrac{W_s}{\gamma_d}$	since both quantities equal V
(7)	Since $W = W_s + W_w$	by definition
(8)	$\dfrac{W_s + W_w}{\gamma_m} = \dfrac{W_s}{\gamma_d}$	substituting for W in (6)
(9)	$W_s(\gamma_m) = (W_s + W_w)\ (\gamma_d)$	cross-multiplying equation (8)
(10)	$\gamma_m = \dfrac{(W_s + W_w)\ \gamma_d}{W_s}$	dividing both sides by W_s

CONTINUED ON NEXT PAGE

(11) $\gamma_m = \left(1 + \frac{W_w}{W_s}\right)\gamma_d$ simplifying equation (10)

(12) since $w = \frac{W_w}{W_s}$ by definition

(13) $\gamma_m = (1+w)\ \gamma_d$ substituting in equation (11)

This completes the derived relationship.
(Note that w would be expressed in decimal form in this derivation.)
This equation may be further re-arranged so that dry unit weight can be calculated from known values of moist unit weight and water content. This is the commonly used calculation form:

$$\gamma_d = \frac{\gamma_m}{(1+w)}$$

It can also be shown in the same manner that:

$\gamma_{sat} = \gamma_d\ (1+w_{sat})$ where w_{sat} is a decimal.

Example:

A moist soil sample weighs 10.2 pounds. Its volume is .08 cubic feet. Its water content was calculated to be 21.3%. Calculate the moist unit weight and dry unit weight.

$$\gamma_m = \frac{W}{V} =$$

$$= \frac{10.2 \text{ pounds}}{0.08 \text{ ft}^3}$$

$$= 127.5 \text{ pounds/ft}^3$$

$$\gamma_d = \frac{\gamma_m}{(1+w)}$$

Convert water content in % to decimal: $w = \frac{21.3\%}{100} = 0.213$

$$\gamma_d = \frac{127.5 \text{ lbs/ft}^3}{(1+0.213)}$$

$$\gamma_d = 105.1 \text{ lbs/ft}^3$$

CONTINUED ON NEXT PAGE

ACTIVITY 9

Problem

1. A soil sample weighs 126 grams in its natural condition, has a volume of 62.0 cubic centimeters, and has a water content of 8.62%. What is its dry unit weight?

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON THE FOLLOWING PAGE

ACTIVITY 9

Solution

$$\gamma_m = \frac{W}{V}$$

$$\gamma_m = \frac{126 \text{ grams}}{62.0 \text{ cm}^3}$$

$$\gamma_m = 2.0323 \text{ g/cm}^3$$

$$\gamma_d = \frac{\gamma_m}{(1+w)}$$

$$\gamma_d = \frac{2.0323 \text{ g/cm}^3}{1.0862}$$

$$\gamma_d = 1.871 \text{ g/cm}^3$$

START THE TAPE WHEN YOU HAVE FINISHED

ACTIVITY 10 - SUPPLEMENTAL DEFINITIONS AND RELATIONSHIPS

Void Ratio, e

Void ratio, designated e, is the ratio of the volume of air and water, or voids, in a soil mass to the volume occupied by the soil solids. It is usually expressed as a decimal.

$$e = \frac{V_v}{V_s}$$

Since volumes are not usually measured, derived relationships are used to calculate e. A useful derived relationship is:

$$e = \frac{G_s \ \gamma_w}{\gamma_d} - 1$$

Values of void ratio for soils may vary between perhaps 0.3 to 3.0 or greater. Most commonly, values are between 0.5 and 1.0. As you can see from the equation, low void ratios represent soils with a low void volume compared to soil solid volume. This means the soil particles are closely packed, or the soil is at a high unit weight. High void ratios are typical of soils which have a large void volume, or low unit weight.

Example

A soil sample weighs 16.2 pounds when moist. Its weight after drying is 13.1 pounds. It's volume is 0.15 cubic feet. Calculate the sample's void ratio. The soil solids' specific gravity is 2.68.

(1) First, determine the sample's water content, w.

$$w(\%) = \frac{W-W_s}{W_s} \times 100$$

$$= \frac{16.2 - 13.1}{13.1} \times 100$$

$$w = 23.7\% \quad \text{(As a decimal } w = 0.237\text{)}$$

(2) Next calculate the moist unit weight, γ_m.

$$\gamma_m = \frac{W}{V}$$

$$= \frac{16.2 \text{ pounds}}{0.15 \text{ ft}^3}$$

$$= 108.0 \text{ pcf}$$

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ACTIVITY 10 - Continued

(3) Calculate the dry unit weight, γ_d.

$$\gamma_d = \frac{\gamma_m}{(1+w)}$$

$$= \frac{108 \text{ pcf}}{1.237}$$

$$= 87.3 \text{ pcf}$$

(4) Calculate void ratio, e.

$$e = \frac{G_s \ \gamma_w}{\gamma_d} - 1$$

Because we are using English system measurements (pounds/cubic feet), γ_w must be in the same units as γ_d or $\gamma_w = 62.4$ lbs/ft^3.

$$e = \frac{(2.68)(62.4)}{(87.3)} - 1$$

$$= 0.916$$

Porosity, n

Porosity, denoted n, is defined as the volume of voids in the soil mass divided by the total volume of the soil mass. It is usually expressed as a percentage.

$$n(\%) = \frac{V_v}{V} \times 100$$

A derived relationship may be used to calculate porosity.

$$n(\%) = \frac{e}{1+e} \times 100$$

CONTINUED ON NEXT PAGE

Example

Using the data from the previous example, calculate the sample's porosity.

(1) Given - $e = 0.916$

(2) $n(\%) = \frac{e}{1+e} \times 100$

(3) $= \frac{0.916}{1.916} \times 100$

(4) $= 47.8\%$

Saturated water content, w_{sat}

The saturated water content of a soil mass is the water content if all the void space is filled with water. Even if a sample is not saturated at present, the water content at saturation can be calculated. It is usually expressed as a percentage. Derived relationships which you may find useful are:

$$w_{sat}\ (\%) = \frac{\gamma_w}{\gamma_d} - \frac{1}{G_s} \times 100$$

Note - units for the unit weight of water, γ_w, and dry unit weight, γ_d, should be compatible.

Another useful relationship for calculating saturated water content is:

$$w_{sat}(\%) = \frac{e}{G_s} \times 100$$

Example

Using the data from the previous example, calculate the sample's theoretical saturated water content.

(1) Given: $e = 0.916$ $G_s = 2.68$

(2) $W_{sat}(\%) = \frac{e}{G_s} \times 100$

$= \frac{0.916}{2.68} \times 100$

$= 34.2\%$

CONTINUED ON NEXT PAGE

ACTIVITY 10 - Continued

Problem:

A soil sample's measured volume is 30.7 cubic inches. The moist weight is 1.87 pounds. The water content was determined by oven drying to be 22.5%. The specific gravity of the soil solids, G_s, is 2.68.

Determine the void ratio, e, the porosity, n, the saturated water content, w_{sat}, and the percent saturation of the sample. Review the definition of percent saturation in Module 4 if necessary.

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON PAGE 32

ACTIVITY 10 - Solution

Given:

$V = 30.7$ cubic inches
$W = 1.87$ pounds
$w(\%) = 22.5\%$ (.225 as a decimal)
$G_s = 2.68$

Step 1 - Change volume, V, to cubic feet
since 1 cubic foot = 1,728 cubic inches
30.7 cubic inches = .01777 cubic feet

Step 2 - $\gamma_m = W/V$
= 1.87 pounds/.01777 cubic foot
= 105.3 pcf

Step 3 - γ_d
$= \gamma_m/(1+w)$
= 105.3 pcf/(1.225)
= 85.9 pcf

Step 4 - $e = (G_s\ \gamma_w/\gamma_d) - 1$
$= (2.68 \times 62.4/85.9) -1$
$= 0.946$

Step 5 - $n(\%) = [e/(1+e)] \times 100$
$= (0.946/1.946) \times 100$
$= 48.6\%$

Step 6 - $w_{sat}(\%) = (e/G_s) \times 100$
$= (0.946/2.68) \times 100$
$= 35.3\%$

Step 7 - $\%S = (w_n(\%)/w_{sat}(\%) \times 100$
$= (22.5/35.3) \times 100$
$= 63.7\%$

START THE TAPE AFTER YOU HAVE FINISHED

Activity 11

The chart on the next page shows basic and derived relationships for volumes and weights of soils. Often, you will have several values from measurements you have made and will need to calculate other parameters. Most of the time, you will find an equation in this chart that will fit your needs.

TURN THE PAGE AND REVIEW THE CHART

Activity 11

Property			Saturated Sample	Unsaturated Sample	Other Useful Equations	
1	2	3	4	5	6	7
Volume Components	V_s	Volume of solids	$V-(V_a+V_w)$		$\frac{W_s}{G_s\gamma_w}$	X
	V_w	Volume of water	V_v-V_a		$\frac{W_w}{\gamma_w}$	X
	V_a	Volume of air	zero	$V-(V_s+V_w)$	V_v-V_w	X
	V_v	Volume of voids	$\frac{W_w}{\gamma_w}$	$V-V_s$	X	X
	V	Total volume	V_s+V_w	$V_s+V_w+V_a$	measured	X
	n	Porosity	$\frac{V_v}{V}$		$\frac{e}{(1+e)}$	X
	e	Void ratio	$\frac{V_v}{V_s}$		$\frac{G_s\gamma_w}{\gamma_d}-1$	$\frac{n}{(1-n)}$
Weights for Specific Sample	W_s	Weight of solids	$W-W_w$		$\frac{W}{(1+w)}$	measured
	W_w	Weight of water	$W-W_s$		wW_s	X
	W	Total weight	W_s+W_w		$W_s\ (1+w)$	measured
	W_{sat}	Saturated weight	$W_s(1+w_{sat})$	X	X	X
	W_{sub}	Submerged weight	$W_s-V_s\gamma_w$	X	$\frac{W_s(G_s-1)}{G_s}$	X
Weights for Sample of Unit Volume	γ_d	Dry unit weight	$\frac{\gamma_{sat}}{1+w_{sat}}$	$\frac{\gamma_m}{1+w_n}$	$\frac{G_s\gamma_w}{1+e}$	X
	γ_m	Moist unit weight	X	$\frac{W_s+W_w}{V}$	$\frac{\gamma_d}{(1+w)}$	X
	γ_{sat}	Saturated unit weight	$\frac{W_s+V_w\gamma_w}{V_v}$	X	$\gamma_d(1+w_{sat})$	$\frac{(G_s+e)\ \gamma_w}{1+e}$
	γ_{sub}	Submerged unit weight	$\gamma_{sat}-\gamma_w$	X	$\frac{\gamma_d(G_s-1)}{G_s}$	X
Combined Relations	w	Water content	X	$\frac{W_w}{W_s}$	$\frac{eS}{G_s}$	X
	w_{sat}	Saturated water content	$\frac{W_{sat}-W_s}{W_s}$	X	$\frac{e}{G_s}$	$\frac{\gamma_w}{\gamma_d}-\frac{1}{G_s}$
	S	Degree of saturation	$V_w=V_v$	$V_w<V_v$	$\frac{w}{w_{sat}}$	$\frac{wG_s}{e}$
	G_s	Specific gravity	$\frac{W_s}{V_s\gamma_w}$		$\frac{\gamma_d(1+e)}{\gamma_w}$	measured

Note: Variables usually expressed as a percentage should be multiplied by 100 from the equations given above.

Activity 12

Usually, 4 basic measurements are made on a soil mass. They are:

(1) Total weight of the sample, W.

(2) Volume of the sample, V.

(3) Weight of the sample after drying, W_s.

(4) Specific gravity of the soil solids, G_s.

Many useful terms may be calculated from this data. The data is usually calculated in the following sequence:

(1) Calculate water content of the sample, w %.

$$w\% = \frac{W-W_s}{W_s} \times 100$$

(2) Calculate moist unit weight, γ_m (saturated unit weight if the sample is saturated).

$$\gamma_m = \frac{W}{V}$$

(3) Calculate the dry unit weight, γ_d.

$$\gamma_d = \frac{\gamma_m}{(1+w)}$$ Where w is a decimal, not a percentage. $w = w(\%)/100$.

(4) Calculate the void ratio, e.

$$e = \frac{G_s \ \gamma_w}{\gamma_d} - 1$$

(5) Calculate saturated water content, w_{sat} (%), and percent saturation, S(%).

$$w_{sat}\% = \frac{e}{G_s} \times 100$$

$$S(\%) = \frac{w\%}{w_{sat}\%} \times 100$$

(6) Calculate saturated unit weight, γ_{sat}.

$\gamma_{sat} = \gamma_d \ (1+w_{sat})$. Where w_{sat} is a decimal, not a percentage.

(7) Other terms such as porosity and values from the block diagram may be calculated from equations in Activity 11.

AFTER COMPLETING THE ACTIVITY, TURN THE PAGE AND COMPLETE ACTIVITY 13

Activity 13

1. Draw a block diagram of a soil mass and label each element's weight and volume and the total weight and volume. Use the symbols you have learned.

2. Unit weight is equal to the ________ of a mass divided by its __________.

3. Write one equation for water content.

4. Water content is usually expressed as a (decimal/percentage). [Cross out the incorrect one.]

5. Specific gravity is the ratio of the ______________________________

____.

6. A saturated soil has a small volume of air. (T/F)

7. Voids are space in a soil sample occupied only by air. (T/F)

8. List the 4 common soil measurements.

   a.
   b.
   c.
   d.

9. A soil mass can contain more water than it takes to fill up its void volume. (T/F).

10. A soil's void ratio cannot exceed 1.0. (T/F).

11. The weight of soil solids in a sample is determined by _______________

____.

12. A range of values for specific gravity of soil solids of a clay soil is

____.

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON THE FOLLOWING PAGE

ACTIVITY 13 - Answers

1. Refer to Activity 2 for completed Block Diagram.

2. Unit weight is equal to the weight of a mass divided by its volume.

3. $w(\%) = \frac{W_w}{W_s} \times 100$ or $w(\%) = \frac{W - W_s}{W_s} \times 100$

4. percentage

5. Specific gravity is the ratio of the unit weight of a substance to the unit weight of water

$$G = \frac{\gamma}{\gamma_w}$$

6. False. A saturated soil has no air.

7. False. Void space in a soil is space occupied by air and water.

8. The four common soil measurements are:
   a. Total weight of sample, W
   b. Dry weight of sample (weight of solids), W_s
   c. Total volume of sample, V
   d. Specific gravity of soil solids, G_s

9. False.

10. False.

11. Weighing the sample after oven-drying at 105°.

12. 2.60-2.80

AFTER YOU HAVE CHECKED YOUR ANSWERS COMPLETE ACTIVITY 14 ON THE NEXT PAGE

ACTIVITY 14 - Solve the two following problems. Equations in Activity 11 and methods learned in Activity 12 may be useful.

1. A sample of soil is taken from an earth fill. The size of hole left after taking the sample is measured to be 0.26 cubic feet. The soil sample weighs 32.4 pounds before drying and weighs 28.8 pounds after drying. The G_s value is 2.68.

   Calculate:

   (a) The moist unit weight of the sample.

   (b) The water content of the sample.

   (c) The dry unit weight of the sample.

   (d) The percent saturation for the sample.

2. A block of soil is carefully measured. It is 26.0 centimeters high 22.0 centimeters long, and 19.7 centimeters wide. It weighs 19,500 grams, and was found to weigh 15,300 grams after drying. The soil's specific gravity is 2.70.

Find:

The sample's (a) void ratio, (b) porosity, and (c) percent saturation.

AFTER COMPLETING THE ACTIVITY, CHECK YOUR ANSWERS ON THE FOLLOWING PAGE

ACTIVITY 14 - Problem 1, Solution

Given $V = 0.26 \text{ ft}^3$
$W = 32.4 \text{ lbs.}$
$W_s = 28.8 \text{ lbs.}$
$G_s = 2.68$

(a) $$\gamma_m = \frac{W}{V}$$

$$= \frac{32.4 \text{ lbs.}}{0.26 \text{ ft}^3}$$

$$= 124.6 \text{ lbs/ft}^3$$

(b) $$w(\%) = \frac{W - W_s}{W_s} \times 100$$

$$= \frac{32.4 - 28.8}{28.8}$$

$$= 12.5\%$$

(c) $$\gamma_d = \frac{W_s}{V}$$

$$= \frac{28.8 \text{ lbs}}{0.26 \text{ ft}^3}$$

$$= 110.8 \text{ lbs/ft}^3$$

(d) $$w_{sat}(\%) = \left[\frac{\gamma_w}{\gamma_d} - \frac{1}{G_s}\right] \times 100$$

$$= \frac{62.4}{110.8} - \frac{1}{2.68} \times 100$$

$$= 19.0\%$$

$$S(\%) = \frac{w(\%)}{w_{sat}(\%)} \times 100$$

$$= \frac{12.5}{19.0} \times 100$$

$$= 65.7\%$$

ACTIVITY 14 - Problem 2, Solution

Given:

Height = 26.0 centimeters

Length = 22.0 centimeters

Width = 19.7 centimeters

$W = 19{,}500$ grams

$W_s = 15{,}300$ grams

$G_s = 2.70$

(a) $V = \text{Length} \times \text{Width} \times \text{Height}$

$= 26 \times 22 \times 19.7$

$= 11{,}268\ cm^3$

$$\gamma_d = \frac{W_s}{V}$$

$$\gamma_d = \frac{15{,}300 \text{ grams}}{11{,}268\ cm^3}$$

$= 1.36\ g/cm^3$

$$e = \frac{G_s\ \gamma_w}{\gamma_d} - 1$$

$$e = \frac{2.70 \times 1.0}{1.36}$$

$e = 0.988$

(b) $$n(\%) = \frac{e}{1+e} \times 100$$

$$n(\%) = \frac{0.989}{1.989} \times 100$$

$n(\%) = 49.7\%$

(c) $$w(\%) = \frac{W-W_s}{W_s} \times 100$$

$$= \frac{19{,}500 - 15{,}300}{15{,}300}$$

$= 27.45\%$

$$w_{sat}(\%) = \frac{e}{G_s} \times 100$$

$$= \frac{0.989}{2.70} \times 100$$

$= 36.6\%$

$$S(\%) = \frac{w(\%)}{w_{sat}(\%)} \times 100$$

$$= \frac{27.45}{36.6} \times 100$$

$= 75.0\%$

START THE PLAYER WHEN YOU HAVE FINISHED

APPENDIX 1

Volume Measurement Techniques

<u>Clod Test</u> - p. 4-29, 4-62 to 4-65, Soil Conservation Service, National Engineering Handbook, Section 19, Construction Inspection, p. 4-117

<u>Sand Cone Test</u> - American Society for Testing Materials, Section 4, Vol. 04.08, D1556

<u>Rubber Balloon Test</u> - American Society for Testing Materials, Section 4, Vol. 04.08, D2167

<u>Drive-Cylinder Test</u> - American Society for Testing Materials, Section 4, Vol. 04.08, D2937

ENG - SOIL MECHANICS TRAINING SERIES

(BASIC SOIL PROPERTIES)

MODULE 4 - VOLUME-WEIGHT RELATIONS

SLIDE - NARRATION

November 1986

SCS Logo

1

Module 4

VOLUME-WEIGHTS RELATIONSHIPS

This module covers the relationships that exist between a soil mass and the volume it occupies. It also discusses the definitions and equations used to express these relationships mathematically. These volume-weight relations provide the basis for most soil mechanics calculations.

2

1. Construct and label a block diagram of a soil mass.

At the completion of this module you will be able to complete the following objectives:

1. Construct and label a block diagram of a soil mass.

3

2. Define conceptually from memory a list of important volume weight relationships.

2. Define conceptually from memory a list of important volume - weight relations.

4

3. Select the proper equations to solve for unknown terms.

3. Select the proper equations from a given reference table to solve for unknown volume-weight terms.

5

4. List the 4 commonly measured laboratory parameters. 6	4. List from memory the four commonly measured laboratory parameters of a soil mass.
ACTIVITY 1 7	These objectives are listed in Activity 1 of your Study Guide. Stop the tape and review these objectives before continuing.
Idealized soil 8	A soil mass consists of a mixture of solid soil particles, water, and air.
air water soil solids 9	If one could separate and condense each of these components and arrange them into three distinct parts, the soil mass could be represented by this hypothetical block diagram. An illustration such as this will be very helpful in explaining the terminology associated with a soil's volume-weight relation. Light blue represents the air. Dark blue represents the water and brown represents the soil solids.
Block Diagram 10	The volume and weights of each of the 3 soil components may be measured by methods covered later in this module.

Block Diagram (Highlight V and W) 11	Dimension lines will be used to identify the volumes and weights of each of the three components. Volumes are shown on the left side and weights on the right side of the block diagram. The total volume will have the symbol, V, and the total weight, the symbol W.
Block Diagram (Highlight V_a, V_w, V_s, V_v) 12	The volume occupied by air is labeled Vee sub a, water is Vee sub w and the solids as Vee sub s. The volume occupied by the air and water is called the volume of the voids or Vee sub vee.
Block Diagram (Highlight W_a, W_w, W_s, W_v) 13	The weight of the air is labeled W sub a, weight of water is W sub w, and the weight of the solids is W sub s. The weight of air, W sub a, is assumed to be zero. Note that the symbol for Weights is a capital W. A lower case w is a symbol used for another quantity covered later in the module.
	If dimension lines are used, one can easily see that certain volume relation can be established.
Block Diagram Highlight Volume 14	The total volume is equal to the volume of the solids plus the volume of the water plus the volume of the air. The total volume is also equal to the volume of the voids plus the volume of the solids.
Block Diagram Highlight Weight 15	In addition, several weight relationships can be established. The total weight of the soil mass is equal to the weight of the solids plus the weight of the water plus the weight of the air. However, we have already stated that the weight of the air is negligible. Therefore, the total weight is equal to the weight of water plus the weight of the solids.

Activity 2

16

Activity 2 in your Study Guide shows a detailed block diagram with lables and definitions of all elements. You should be able to reproduce this diagram from memory. Stop the tape and carefully study Activity 2.

Direct Soil Measurements Block Diagram with V, W, and W_s highlighted.

17

Three of the quantities on this diagram can be measured directly. These measurements are frequently made in laboratories and in the field. The three block diagram quantities commonly directly measured are covered in the following slides.

V=6"x6"x6"=216 cubic inches.

18

The first directly measured block diagram quantity is the total volume, V, of a soil mass. It may be measured in several ways. The simplest way is to carve a sample of known volume from a larger soil mass. For instance, if you carve a cube of soil exactly 6" on a side, the volume would be 216 cubic inches. Volumes are commonly expressed in units of cubic inches, cubic feet, cubic yards, cubic meters, or cubic centimeters.

Photo

19

Frequently, cylindrical samples of soil are used. The volume of a cylindrical specimen may be calculated if its diameter/pause/and length/pause/are known.

$|\leftarrow D \rightarrow|$

$\updownarrow L$

$$V = \frac{\pi D^2}{4} \times L$$

20

The volume of a cylindrical sample is calculated from this equation using measured values of diameter, D, and length, L.

ACTIVITY 3

21

Activity 3 in the Study Guide covers the calculation of specimen volumes. Stop and complete this Activity before continuing.

OTHER VOLUME MEASUREMENT PROCEDURES	A number of other procedures are available for indirectly determining the volume of an irregularly shaped soil mass.
22	
Photo 23	The clod test is a means of indirectly measuring an irregular soil mass. A soil clod is first weighed in air.
Photo 24	The clod is then coated with wax/pause/and reweighed to determine the volume of wax added to the soil volume.
Photo 25	
Photo	The clod and wax are then weighed submersed in water. According to Archimedes principal, the difference of the weight in air and the submersed weight of the object is equal to the weight of the volume of water displaced.
26	Since water has a known weight, the volume of the clod may be accurately determined by this method.
Photo 27	Another common method of measuring a soil mass's volume is the sand cone test. A soil mass is first removed from an area to be tested, leaving a uniform hole.
Photo 28	The weight of sand required to fill the hole left by the removed soil is carefully determined.
Photo 29	Using calibrated sand, the weight of sand can be converted to volume, thereby indirectly determining the volume of the soil mass removed from the hole. Details for performing these tests are shown in an Appendix in your Study Guide.
$W = W_S + W_W$ 30	The second block diagram quantity commonly measured is the total weight, W, of a soil mass.

Photo

It is determined simply by weighing the mass. Units of measurement may be in ounces, pounds, grams, kilograms, or others. Note that both the weight of the soil solids and any water in the soil are included.

31

Air weight is negligible.

Weight
Solids = W_s
Dry Weight

32

The third measured block diagram quantity is the weight of solids, W sub s. It is the oven-dry weight of a soil sample. Oven drying for most soils is accomplished at a temperature of 105 degrees centigrade. Samples are dried until no further weight loss occurs.

Photo

33

Soils are dried in an oven with precise temperature control using containers not affected by the temperatures used. Samples are usually dried overnight.

Weight water =
Total weight -
Dry weight =
$W_w = W - W_s$

34

The weight of water, W sub w, in a soil mass is the difference in the weight of the sample before drying and that after drying.

Unit
Weight

$\gamma = \frac{W}{V}$

35

Relationships between individual weights and volumes in the block diagram will now be discussed. The first term to be defined is unit weight.

Unit weight of a substance is the weight of the object divided by the volume of the object. It is usually designated with the Greek letter gamma.

Unit Weight of water

$$\gamma_w = 62.4 \frac{\text{pounds}}{\text{cubic foot}}$$

or

1.0 grams/cubic centimeter

36

Water is a very uniform substance. The unit weight of pure water, gamma sub w, at 20 degrees centigrade is 62.4 pounds per cubic foot in English units. In Metric units, it is 1.0 grams per cubic centimeter.

Since $\gamma_w = \frac{W_w}{V_w}$

Then

$$V_w = \frac{W_w}{\gamma_w}$$

37

The concept of unit weight provides a valuable tool for indirectly determining the volume of a substance. From the definition, you can see that the volume of water may be calculated if the measured weight of the water and the unit weight of the water are known.

Activity 4

38

Activity 4 in your Study Guide illustrates this concept. Stop the tape and complete this Activity.

$$G = \frac{\gamma}{\gamma_w}$$

39

The fourth commonly measured parameter used in volume weight relations is specific gravity. Specific gravity may be defined as the ratio of the unit weight of a substance to the unit weight of water. For instance, if a substance has a specific gravity of 3, its unit weight is 3 times that of water.

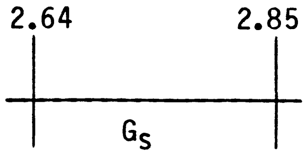
Specific gravity of Solids

$$G_s = \frac{W_s/V_s}{\gamma_w}$$

40

Specific gravity of soil solids then may be visualized as the ratio of the unit weight of a solid mass of condensed soil solids to the unit weight of distilled water. The specific gravity of the soil solids is appreviated as Gee-sub-ess. A laboratory test is used to measure this value for soils.

Common Values of G_s for Soils



41

Activity 5 covers in detail the definition of specific gravity. It also lists a range of commonly measured specific gravity values for various soils. Pure quartz, for instance, has a specific gravity of 2.66. This means a solid chunk of quartz weighs 2.66 times as much as an equal volume of water. Stop and carefully study this Activity.

$$G = \frac{W/V}{(W/V)\ \text{water}}$$

42

Specific gravity provides a very convenient way of indirectly determining the volume of a substance from its weight. Usually, a mass can be weighed easier than its volume determined, especially if the mass is irregularly shaped. Using this equation, we can determine the volume of a mass after weighing the substance since volume is the only unknown term in the equation, if we know the specific gravity of the substance.

$$V_s = \frac{W_s}{G_s\ \gamma_w}$$

43

Extending this concept, it may be seen from the given equation that you can determine the volume of soil solids in a mass if you know their weight, the value of their specific gravity, and the unit weight of water. Remember that the value of G sub s, the soil solids' specific gravity, can either be measured in a laboratory, or estimated.

Activity 6

44

Activity 6 in your Study Guide has examples and problems illustrating this concept. Stop and complete this activity.

Four Basic Measurements

W, W_s, V, G_s

45

You now have procedures for obtaining all of the terms in a block diagram using 4 basic measurements. The 4 basic measurements are: (1) Total weight, W (2) Dry weight, W sub ess. (3) Total volume, V, and (4) specific gravity, of the soil solids, Gee sub ess. There are some additional relationships and definitions derived from these basic terms that are also important.

Water Content

$$w(\%) = \frac{W_w}{W_s} \times 100$$

46

Water content is defined as the ratio of the weight of water in a soil mass divided by the weight of the soil solids in the mass, expressed as a percentage. The calculated value for water content may exceed 100% in some soils. Values as high as 300%-400% are possible. Note that the symbol for water content is a lower case w. You should recall that a capital letter W is used for total weight of a soil sample.

Activity 7

47

Activity 7 in the Study Guide details the measurements and calculations needed to determine water content. Stop and complete this Activity

You may also want to refer to Activity 9; contained in the Study Guide for Module 1, Part A, Soil Mechanics Level I, for a detailed discussion of this term.

Block Diagram showing $V_w = V_v$

48

Remember, the volume of the voids in a soil mass may contain both air and water. If water has replaced all of the air, then the volume of voids is equal to the volume of water. When this occurs, the soil is completely saturated.

Water Contents

w_n - natural water content

w_{sat} - saturated water content

49

The natural water content of a soil is denoted w sub n. Water contents measured from saturated samples are denoted w sub sat. This may also be a theoretical value as covered later in the module.

$$\%\ Sat = \frac{V_w}{V_v} \times 100$$

50

Percent saturation is the volume of the water in a soil mass divided by the volume of the voids. It is expressed as a percentage. Percent saturation may not exceed 100 percent, because when the void space is filled with water, any additional water would be free water outside the sample.

$$\%\ Sat = \frac{w_n\ \%}{w_{sat}\ \%} \times 100$$

51

Percent saturation may also be defined as the ratio of the natural water content measured to the theoretical saturated water content. It is expressed as a percent. A soil mass is 100% saturated if its measured water content equals its theoretical saturated water content.

Unit Weight

$$\gamma = \frac{W}{V}$$

52

Frequently the unit weight of a soil mass must be calculated. As you will recall, unit weight is defined as the weight divided by the volume. Unit weight is calculated using this equation:

Types of Unit Weight

Dry
Moist
Saturated

53

The unit weight of a soil mass can vary depending upon its wate content. Three basic ones are used. They are: dry unit weight, moist unit weight, and saturated unit weight.

Dry Unit Weight

$$\gamma_d = W_s/V$$

54

Dry Unit Weight is the weight of the soil particles or soil solids, in a soil mass divided by the total volume of the soil mass. It is expressed as gamma sub d. Remember the weight of soil solids is the oven dry weight of the sample.

Moist Unit Weight

$$\gamma_m = \frac{W}{V}$$

55

Moist Unit Weight is the total weight of a soil mass divided by its volume. It is designated as gamma sub m. It refers to measurements made on a moist soil (not saturated).

Saturated Unit Weight

$$\gamma_{sat} = \frac{W}{V}$$

56

Saturated Unit Weight is the total weight of a saturated soil mass divided by its volume. It is designated as gamma sub sat.

$\gamma_b = \gamma_{sat} - \gamma_w$ 57	Buoyant Unit Weight is the submerged unit weight of a saturated sample. It is calculated using this equation.
Activity 8 58	Activity 8 in your Study Guide defines these terms and has examples and problems on calculating the values. Stop the tape and complete this activity before continuing.
Relationship of Unit Weights and Water Content 59	Equations can be derived giving the relationships between unit weights and water contents. These are mathematical derivations based on the block diagram quantities.
Activity 9 $\gamma_d = \frac{\gamma_m}{(1+w)}$ 60	Activity 9 in the Study Guide illustrates one of these derived relationships. Stop the tape and study this information.
Other Terms 61	A number of additional terms and equations are used in soil mechanics. The more important terms are defined in the next slides. They are also related to the block diagram.
Void Ratio $e = \frac{V_v}{V_s}$ 62	Void ratio, small e, is defined as the volume of the void space in a sample divided by the volume occupied by soil solids. It is usually expressed as a decimal, such as 0.68 or 1.43. A soil mass which has a volume of voids equal to the volume occupied by solids would have a void ratio of 1.0. Soils may have void ratios as low as three tenths to as high as three or greater.

Void Ratio $e = \frac{G_s \gamma_w}{\gamma_d} - 1$ 63	Since the volume of voids and volume of solids are not usually directly measured, it is more convenient to express void ratio in terms of parameters which <u>are</u> measured. The equation shown is commonly used. Derivation of the equation is based on basic block diagram relationships. Note that unit weight values for water and dry unit weight of the sample must be in the same units when using this equation.
Porosity $n(\%) = \frac{V_v}{V} \times 100$ 64	Porosity, small n, is the volume of voids in a soil sample divided by the total volume. It is usually expressed as a percentage such as 57%.
Porosity $n = \frac{e}{1+e} \times 100$ 65	Porosity is usually calculated from the relationship shown. A soil with a porosity of 50% has a void ratio of 1.0. That is, the volume of voids equals the volume of solids.
Saturated Water Content w_{sat} (%) 66	Sometimes one needs to know what the water content of a soil mass would be at saturation even though the sample presently is not saturated. Equations are available for calculating the theoretical saturated water content. They are derived in the same way as the derivation given in Activity 8.
$w_{sat}(\%) = \frac{\gamma_w}{\gamma_d} - \frac{1}{G_s} \times 100$ $w_{sat}(\%) = \frac{e}{G_s} \times 100$ 67	These two equations are useful for calculating saturated water content using commonly measured parameters. Activity 10 has definitions, examples, and problems for void ratio, porosity, and saturated water content. Stop the tape and complete this activity before continuing.

Activity 11

Activity 11 lists a number of other useful relationships. Some are based on definitions and the block diagram. Others are derived relationships. Stop and study this Activity before continuting.

68

Review

1. Total Weight of Mass.
2. Dry Weight of Mass.
3. Volume of Mass.
4. Specific Gravity of Soil.

Let us review now. Only a few basic measurements are needed to calculate many useful terms relating to a soil mass. The 4 measurements commonly made are (1) Total weight of the soil mass. This includes soil particles and the weight of water in the soil. (2) Dry weight is measured after oven-drying the sample and is the soil solids' weight only. (3) Volume of the mass is determined by several different techniques. It is the total volume of the sample. (4) Specific gravity of the soil solids is a laboratory test but may often be estimated with sufficient accuracy.

69

Activity 12
Activity 13
Activity 14

Activity 12, 13, and 14 have information on problem-solving techniques and review problems. Complete those activities to review your understanding of volume-weight problems.

70

Construct and label block diagram of a soil mass.

Let's review the objectives to ensure that you have accomplished all of them. You should be able to:

1. Construct and label a block diagram of a soil mass.

71

2. Define conceptually from memory a list of important volume weight relationships.

2. Define conceptually from memory a list of important volume - weight relations.

72

3. Select the proper equations to solve for unknown terms. 73	3. Select the proper equations from a given reference table to solve for unknown volume-weight terms.
4. List the 4 commonly measured laboratory parameters. 74	4. List from memory the 4 commonly measured laboratory parameters of a soil mass.
The End 75	Congratulations upon completion of this module. If for some reason you have any questions or had a problem with a particular activity, review the module. If not, you are ready to continue to Module 5.

ENG - SOIL MECHANICS TRAINING SERIES

(BASIC SOIL PROPERTIES)

MODULE 4 - VOLUME-WEIGHT RELATIONS

CERTIFICATION OF COMPLETION

This certifies that ______________________________ completed Module 4 - Volume-Weight Relations of the ENG - Soil Mechanics Series (Basic Soil Properties) ____________________ (date) and is credited six hours of training.

Signed ______________________________ Supervisor/Trainer

Signed ______________________________ Participant

Completion of Module 4 - Volume-Weight Relations of the ENG - Soil Mechanics Series (Basic Soil Properties) is acknowledged and documented in the above named employee's training record.

Signed ______________________________ State Training Officer

______________________________ Date